GUIDE NO. AERB/NPP-WCR/SG/D-26

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GOVERNMENT OF INDIA

AERB SAFETY GUIDE

ACCIDENT MANAGEMENT PROGRAMME FOR WATER COOLED REACTOR BASED NUCLEAR POWER PLANTS

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY GUIDE: AERB/NPP-WCR/SG/D-26

ACCIDENT MANAGEMENT PROGRAMME FOR WATER COOLED REACTOR BASED NUCLEAR POWER PLANTS

Atomic Energy Regulatory Board
Mumbai-400094
India

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FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act, 1962. In pursuance of ensuring safety of members of the public and occupational workers as well as protection of the environment, the Atomic Energy Regulatory Board (AERB) has been entrusted with the responsibility of laying down safety standards and enforcing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, safety codes and related guides and manuals. While some of these documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulatory aspects of these facilities.

AERB Safety codes and safety standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific equipment, structures, systems and components of nuclear and radiation facilities. Safety codes establish the objectives and set requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides and guidelines elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field.

Accident management is an element of the defence in depth and is part of the design of new reactors and operation of the existing reactors. AERB safety codes on operation and design require the accident management guidelines to be developed by the utilities. This safety guide provides guidance to the utilities in the development of accident management programme including severe accident management guidelines. This safety guide specifies the goals and guidance which would help the utilities in developing and implementation of the accident management guidelines. In drafting this document, the relevant AERB Safety Codes on Design and Operation and International Atomic Energy Agency (IAEA) documents on development and implementation of Severe Accident Management Programmes for Nuclear Power Plants have been used. Canadian regulatory document on accident management and other regulatory documents have been referred. In addition, IAEA report on accident management insights after Fukushima Daiichi NPP accident and Nuclear Energy Agency (NEA) report of task group on accident management have also been referred.

A working group consisting of AERB staff and other professionals experienced in this field has prepared this guide. Experts have reviewed the guide and the relevant AERB advisory committees have further reviewed it before issue.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the document and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.

(G. Nageswara Rao)
Chairman, AERB

SPECIAL DEFINITIONS

Additional Safety Systems/Features
Items designed to perform a safety function or which has a safety function in design extension conditions without core melt.

Accident Conditions
Deviations from normal operation which are less frequent and more severe than anticipated operational occurrences, and which include design basis accidents and design extension conditions.

Accident Management
Actions carried out during the evolution of design extension conditions:
(a) to prevent the escalation of the event into a severe accident;
(b) to mitigate the consequences of a severe accident;
(c) to achieve a long term safe stable state.
The second aspect of accident management (to mitigate the consequences of a severe accident) is also termed severe accident management.

Accident Management Programme
An accident management programme consists of all activities and processes developed and undertaken by an operating organization for the prevention and mitigation of accidents. Severe accident management programmes are focused solely on the mitigation of severe accidents.

Complementary Safety Features
A design feature outside of the design basis envelope that is introduced to cope with design extension conditions with core melt/severe accidents.

Computational Aid
Pre-calculated analyses, nomographs or easily usable computer software available for use by plant staff during accident management (i) to guide and support plant staff (ii) to predict accident phenomena and timing and (iii) to evaluate the effectiveness of specific candidate strategies.

Controlled State
This is a state of the plant, following an anticipated operational occurrence or accident condition, in which the fundamental safety functions can be ensured and can be maintained for a time sufficient to implement provisions to reach a safe state/safe shutdown state.

Core Damage
Significant core degradation or severe core damage or core damage for PHWRs:
Loss of structural integrity of more than one coolant channel.

Core melt/core damage for LWRs:
Loss of coolable geometry resulted due to loss of coolant and simultaneous loss of SSCs provided for the core cooling.

Design Basis Accident
Accident conditions against which a nuclear power plant is designed according to established design criteria (including single failure criteria), and for which the damage to the fuel and the release of radioactive material are kept within authorised limits.

Design Extension Conditions
Accident conditions that are not considered for design basis accidents, but that are considered in the design process of the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits. Design extension conditions could include severe accident conditions.

Long-term Safe Stable State
A state in which fuel in the core[1] or the spent fuel pool is submerged in water, the associated reactivity is controlled to remain subcritical, and a long-term decay heat removal from the fuel is achieved and maintained.

Mitigatory Action
Actions (i) to reduce the potential for conditions to develop that would result in exposure or a release of radioactive material requiring emergency actions on or off the site; or (ii) to mitigate source conditions that may result in exposure or a release of radioactive material requiring emergency actions on or off the site.

Onsite Emergency Response Organization (or any equivalent organization)
An organization consisting of group of dedicated personnel who evaluate, decide and execute actions of accident management and emergency response.

Plant States

<table>
<tr><th colspan="2">Operational States</th><th colspan="4">Accident Conditions</th></tr>
<tr><td rowspan="2">Normal operations</td><td rowspan="2">Anticipated operational occurrences</td><td rowspan="2">Design basis accidents</td><td colspan="2">Design extension conditions</td><td>Practically eliminated conditions</td></tr>
<tr><td>Accidents without significant core/fuel* degradation</td><td>Accidents with core melt/significant core degradation@</td><td>Early or large release of radioactivity from containment</td></tr>
<tr><td colspan="5">Considered in design</td><td></td></tr>
<tr><td colspan="4"></td><td colspan="2">Severe accidents</td></tr>
</table>

*'Fuel' word is used here to address the spent fuel pool events
@ 'Fuel' word is not used here as accidents with fuel melt are practically eliminated in spent fuel pool. 'Core melt' terminology is applicable for LWRs whereas 'significant core degradation' is applicable for PHWRs

Safe Shutdown State
Safe shutdown state is the state of the plant, following an anticipated operational occurrence or accident conditions, in which the fundamental safety functions can be ensured and maintained

[1] Refer the definitions of safe state and severe accident safe state as applicable for the reactor core/corium.

continuously (Section 5.20.2 of AERB Safety Code on Design of Light Water Reactor based Nuclear Power Plants, AERB/NPP-LWR/SC/D may be referred for further details).

Safe State
State of plant, following design extension condition without core melt, in which the reactor is subcritical and the fundamental safety functions can be ensured and maintained stable for a long time (Section 5.20.3 of AERB Safety Code on Design of Light Water Reactor based Nuclear Power Plants, AERB/NPP-LWR/SC/D may be referred for further details).

Severe Accident
An accident more severe than a design-basis accident and involving severe core degradation in the reactor core or fuel degradation in the spent fuel pool.

Severe Accident Management Guidelines
A set of guidelines for actions for severe accident management.

Severe Accident Preventive Guidelines
A set of guidelines for actions to fulfill the accident management objective of 'preventing core damage' are termed as Severe Accident Prevention Guidelines.

Severe Accident Safe State
Severe accident safe state is a state, which shall be achieved subsequent to a design extension condition with significant core damage or core melt phenomena. Severe accident safe state shall be reached at the earliest after an accident initiation. It should be possible to maintain this state indefinitely. During this state there is (Section 5.20.4of AERB Safety Code on Design of Light Water Reactor based Nuclear Power Plants, AERB/NPP-LWR/SC/D may be referred for further details):

a) no possibility of re-criticality
b) fuel or debris is continuously cooled
c) uncontrolled release of radioactivity to environment is arrested
d) means to maintain above conditions are available for long term, including critical parameter monitoring
e) monitoring of radiological releases and containment conditions

Symptom based procedure/guideline
A procedure or guideline for actions to be taken depending on the values of directly measurable plant parameters.

Verification (for procedures and guidelines)
Verification is a process to confirm the correctness of a written procedure or guideline and to ensure that organisational, technical and human factors have been properly incorporated.

Validation (for procedures and guidelines)
Validation is a process to confirm that the actions specified in the procedures and guidelines can be followed by trained staff to manage emergency events.

CONTENTS

1 INTRODUCTION

1.1 General

In nuclear power plant design, defence in depth is achieved through five levels. Level-1: prevention of deviations from normal operation and the failure of items important to safety, Level-2: detecting and control of deviations from normal operational states in order to prevent anticipated operational occurrences at the plant from escalating to accident conditions, Level-3: prevention of damage to the reactor core/irradiated fuel or significant off-site releases and returning the plant to a safe shutdown state in case of a design basis accident by means of inherent and/or design provisions, safety systems and procedures. Level-4: prevention of extensive fuel damage or core melt (design extension conditions without core melt) through additional safety systems/features and limit the consequences of accident conditions with core melt (design extension conditions with core melt) by means of complementary safety features,Level-5: mitigating the radiological consequences of radioactive releases that could potentially result from accident conditions through emergency response measures such as emergency plans and facilities for on-site and off-site emergency response. The mapping between plant states, defence in depth and other characteristics are shown in Figure 1.

Accident management is one of the key components of effective defence in depth, especially for the fourth level of defence in depth. A set of actions taken during the evolution of accident progression during design extension conditions (DEC) viz. i) to prevent the escalation of the event into a severe accident ii) to mitigate the consequences of a severe accident iii) maintaining the integrity of the containment iv) minimising the releases of radioactive material v) to achieve a safe state/severe accident safe state is termed as 'Accident Management'. A comprehensive accident management programme (AMP) with plant specific information is necessary for performing these functions.

1.2 Objective

This safety guide provides primarily guidance to licensee/applicant for development, implementation, evaluation and updation of the accident management program for nuclear power plants.

1.3 Scope

This safety guide is primarily for the use in the development of accident management programme for water cooled reactors (light water and heavy water cooled reactors). The guidelines are not only applicable for accident management during at-power states, but are intended to be valid also for other modes of operation, including shutdown state. Guidance on accident management for spent fuel pools (SFP) is also covered. Preventive and mitigatory domains of accident management are covered in this guide.

The recommendations of this Safety Guide may also be applied with judgement to other types of nuclear installations, including research reactors and nuclear fuel cycle facilities (including facilities for the storage of spent nuclear fuel). The principles elaborated in this safety guide are also applicable to other types of NPPs.

This document deals with the accident management aspects and interface between accident management programme and emergency response. However, it does not include guidance on emergency preparedness and response.

Plant States	Normal Operation	AOOs	DBAs	DECs		Practically eliminated conditions (Early or large releases)
				without significant core/fuel degradation	with core melt/significant core degradation	
Defence in Depth	Level-1	Level-2	Level-3	Level-4		
					Level-5	
Objective	Prevention of deviations from normal operation	Control of abnormal operation	Control of accidents within design limits	Management to avoid severe core damage/Significant core/fuel degradation	Mitigation to confine radioactive releases	Mitigating the radiological consequences of radioactive releases
Procedures/ Guidelines	Operating Procedures	Emergency Operating Procedures		Emergency Operating Procedures/Severe Accident Preventive Guidelines	Severe Accident Management Guidelines	Use of SAMGs, if applicable
				Accident Management		
			Emergency Response Plans and Procedures			
Systems	Process Systems	Control Systems	Safety Systems	Additional Safety Systems/Features	Complementary Safety Features	Contingency Measures
Response from	Main or Supplementary Control Room					
				Onsite Emergency Support Center		
					Off-site Emergency Response Control Center	

Figure 1: Plant states, defence in depth and their characteristics

2 GENERAL ASPECTS OF ACCIDENT MANAGEMENT PROGRAMME

2.1 Relevant AERB Requirements for Accident Management Programme

2.1.1 AERB Safety Code ‘Design of Pressurised Heavy Water Reactor Based Nuclear Power Plants Section 5.2.11 of AERB/NPP-PHWR/SC/D (Rev.1), 2009’ specifies that accident management procedures shall be established, taking into account representative and dominant severe accident scenarios.

2.1.2 AERB Safety Code ‘Nuclear Power Plant Operation [Section 7.2.3 of AERB/NPP/SC/O (Rev. 1), 2008)]’brings out the requirements on the development of emergency operating procedures or guidance for managing severe accidents.

2.1.3 AERB safety Code ‘Design of Light Water Reactor Based Nuclear Power Plants (Section 7 of AERB/NPP-LWR/SC-D, 2015)’ establishes requirements for additional support provisions for accident management infrastructure needed to handle extreme events along with unexpected failure of existing safety systems/features.

2.1.4 AERB safety Code ‘Design of Light Water Reactor Based Nuclear Power Plants (Section 5.18.5 of AERB/NPP-LWR/SC-D, 2015) requires that severe accident management guidelines (SAMG) shall be prepared, taking into account the plant design features and the understanding of accident progression and associated phenomena.

2.1.5 Accident response capability should be diverse and flexible that would provide a backup to permanently installed plant equipment, that might be unavailable following certain extreme conditions (e.g. extreme natural phenomena such as earthquakes, flooding and high winds), and would supplement the equipment already available for responding to severe accidents. The approach shall include design measures to provide multiple means of obtaining power and water needed to fulfil the key safety functions of maintaining core cooling, containment integrity and spent fuel pool cooling (Section7.2.1 of AERB/NPP-LWR/SC-D, 2015).

2.1.6 Accident management techniques that improve the capability of a plant to survive an extended loss of all AC power, loss of normal heat sinks and loss of normal access to plant site, etc., as a result of extreme events should be developed. It shall include equipment to respond to such challenges; procedures and guidance; equipment readiness, storage, and transportation; and training. The increased equipment capability will consist of installed equipment, portable equipment stored onsite and portable equipment in nearby establishments and other national facilities (Section7.3 of AERB/NPP-LWR/SC-D).

2.1.7 The licensee of the facility or activity shall have arrangements to promptly decide and take on-site actions that are necessary to mitigate the consequences of a nuclear or radiological emergency. These arrangements shall include emergency operating procedures and technical guidance for operating personnel on mitigatory actions. This shall also include, on-site teams at the facility for mitigating the consequences of an emergency (e.g. damage control, firefighting) (Clause 5.3.1 of the R0 draft of AERB code on management of nuclear and radiological emergency, AERB/SC-NRE).

2.2 Objectives for Accident Management

2.2.1 In operating a nuclear power plant, safety of plant personnel, the public and the environment should be ensured. This is achieved by fulfilling the following safety functions:

a) control of reactivity
b) removal of heat from the fuel and/or fuel debris
c) confinement of radioactive material
d) shielding against radiation
e) control of radioactive discharges and hazardous substances, as well as limitation of accidental releases
f) monitoring of safety-critical parameters to guide operator actions

2.2.2 Accident management program is developed to support the fulfillment of the safety functions mentioned above with the following objectives:

a) Preventing or delaying the occurrence of severe fuel/core damage[2].
b) Terminating the progress of severe fuel/core damage once it has started
c) Maintaining the integrity of reactor vessel/calandria to prevent melt through
d) Maintaining the integrity of the containment and preventing containment by-pass
e) Minimizing releases of radioactive material from the core or at other locations of fuel
f) Achieving a long term safe state/severe accident safe state of the reactor core/corium and long term safe stable state of the spent fuel storage

2.3 Concept of Accident Management Programme

2.3.1 A structured top down approach should be used to develop the accident management programme. This approach should begin with the objectives and strategies followed by measures to implement the strategies and finally result in procedures and guidelines. Figure 2 illustrates the top down approach to accident management.

2.3.2 Multiple strategies should be developed to achieve the objectives of accident management (Refer 2.2.2).

2.3.3 From the strategies, suitable and effective measures for accident management should be derived, corresponding to available plant hardware provisions. Such measures may include plant modifications/additional provisions. Personnel actions initiated either in the control room or other locations could be an important part of these measures. Measures could also include use of systems and equipment still available, recovery of failed equipment and use of non-permanent equipment, stored on-site or off-site.

2.3.4 The accident management should cover both preventive and mitigatory domains. In the preventive domain, the guidance should generally consist of descriptive steps, as the plant status is known from the available instrumentation and the consequences of actions can be predetermined by appropriate analysis. The guidance for the preventive domain, therefore should generally be in the form of procedures, usually called emergency

[2] Maintaining the integrity of coolant channels for PHWRs

operating procedures (EOP) which are prescriptive in nature or severe accident preventive guidelines.

2.3.5 In the mitigatory domain, large uncertainties may exist in the plant status, availability of the systems, timing and outcome of actions. Consequently, the guidance for the mitigatory domain should not be prescriptive in nature but rather should include a range of potential mitigatory actions and should allow for additional evaluation and alternative actions. Such guidance is usually called Severe Accident management Guidelines (SAMG).

2.3.6 The guidance for the mitigatory domain should be presented in the appropriate form, including guidelines, procedures, manuals or handbooks. The guidelines/procedures include a set of strategies and measures that describe the tasks to be executed at the plant. Manuals or handbooks typically contain a more general description of the tasks to be executed and their justification.

2.4 General Requirements for Developing Accident Management Programme

Identification of Plant Vulnerabilities and Capabilities

2.4.1 The accident management programme should address internal and external events relevant for the site considered under all modes of operation (including shutdown state) and also events that could cause fuel damage in spent fuel pool, taking into account possible dependencies between events. It should also consider external events that could result in significant damage to the infrastructure on-site or off-site.

2.4.2 Selection of events/accident sequences should be sufficiently comprehensive. This should consider events and accident sequences that could arise from multiple hardware failures, human errors, internal and external hazards, and their combinations. Useful guidance can be obtained from Level-1 PSA, from expert judgement or similar studies from other plants and operating experience from the affected plants.

2.4.3 Full spectrum of challenges (accident sequences, associated phenomena etc.) that can threaten the integrity of the containment and the release of radioactive material to the environment should be identified. Useful guidance can be obtained from the Level-2 PSA, or similar studies from other plants, expert judgment and insights from research on severe accidents.

2.4.4 Low numerical risk estimates (e.g. event/event sequence frequency contributing to core damage frequency or large release frequency) should not be used as the sole basis for excluding events/accident sequences from consideration for SAMG development. This is especially important if the consequences are very high.

Capabilities of the plant/site to cope with the challenges should be identified in performing accident management actions. Accident management provisions need to be comprehensive, well designed and up to date. They need to be derived on the basis of a comprehensive set of initiating events and plant conditions and also need to provide for accidents that affect several units at a multi-unit site.

Development of Accident Management Programme and Guidelines

2.4.5 Plant specific accident management programme should be developed, implemented and maintained consistent with the plant design and its current configuration.

<table>
<tr><td colspan="2"></td><td colspan="2">Design extension conditions (DEC)</td></tr>
<tr><td colspan="2"></td><td>without significant core/fuel degradation</td><td>with core melt / significant core degradation</td></tr>
<tr><td colspan="2" rowspan="2">Safety objective</td><td colspan="2">Level-4 Defence In Depth</td></tr>
<tr><td>Prevent significant fuel degradation and keep releases within acceptable limits</td><td>Terminating the progression of core melt. Maintain the integrity of the containment as long as possible. Minimise on-site and off-site releases.</td></tr>
<tr><td colspan="2">Accident management domain</td><td>Preventive</td><td>Mitigative</td></tr>
<tr><td rowspan="2">Measures</td><td>Systems by design</td><td>Additional safety systems/features</td><td>Complementary safety features</td></tr>
<tr><td>Additional means</td><td colspan="2">Plant modifications, additional provisions, recovery of failed equipment, use of non-permanent systems, personnel actions etc., as applicable.</td></tr>
<tr><td colspan="2">Procedures/Guidelines</td><td>Emergency Operating Procedures/Severe Accident Preventive Guidelines</td><td>Severe Accident Management Guidelines</td></tr>
<tr><td rowspan="2">Analysis in support of AMG</td><td>Deterministic safety analysis (DSA)</td><td>Plant specific analysis</td><td>Plant specific analysis</td></tr>
<tr><td>Probabilistic safety assessment (PSA)</td><td>Level-1 PSA</td><td>Level-1 and 2 PSA</td></tr>
<tr><td colspan="2">Equipment and instrumentation</td><td colspan="2">Qualification/
Survivability as applicable</td></tr>
</table>

TOP DOWN APPROACH

Figure 2: Top down approach and other characteristics for accident management

2.4.6 When developing guidance on accident management, consideration may be given to the full capabilities of the plant. Care should be taken if the possible use of some systems beyond their originally intended function is foreseen in the guidance on accident management.

2.4.7 Development of accident management guidance should be based on best estimate analysis of the physical response of the plant (Refer AERB/SG/D-19 for further details on methodology). While developing the accident management guidance, consideration should be given to uncertainties in knowledge about the timing and magnitude of phenomena that might occur in the progression of the accident.

2.4.8 The approach in accident management should be, as far as feasible, based on either directly measurable plant parameters[3] or information derived from simple calculations and should consider the loss or unreliability of indication of key plant parameters.

2.4.9 The personnel who will be working in the control room or onsite emergency support center (OESC) or any other organizational unit responsible for evaluation, decision-making and implementation in the course of an accident should be involved at an early stage of development of an accident management programme as this provides valuable training for future tasks and feedback. A team of experts with sufficient range and level of expertise should be formed for the development of accident management programme. The team should contain staff responsible for the development and implementation of the accident management programme in the plant, including, analysts, personnel from the training department, operation, maintenance, radiation protection, instrumentation and controls staff, engineering staff, persons responsible for emergency preparedness and response (EPR) planning and external experts, as appropriate.

2.4.10 Multi-unit damage, uncovered fuel in spent fuel pools, releases of radioactive materials and hydrogen into buildings adjacent to the containment should be considered in the development of accident management programme.

2.4.11 Care should be taken when adapting a generic accident management programme to a plant specific one. This should include evaluation for additional vulnerabilities and respective strategies for mitigation. On the other hand, any deviations from generic accident management guidance or plant operating requirements/conditions should receive a rigorous review that considers the basis and benefits of the original approach and the potential unintended consequences of deviating from this approach.

Procedures and Guidelines

2.4.12 Guidance in the form of EOPs or severe accident preventive guidelines should be used in the preventive domain (design extension conditions without core melt) of accident management. Guidelines in the form of SAMGs should be used in the mitigatory domain (design extension conditions with core melt) of accident management.

2.4.13 EOPs/severe accident preventive guidelines should be accomplished by plant operation staff generally from the main control room (MCR) and SAMGs should be accomplished by onsite emergency response organization by identified emergency response team from identified locations.

2.4.14 The plant parameters and their thresholds that define the transition from EOP to preventive guidelines/SAMG should be identified.

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[3] In case of unavailability of direct measurement, it can be derived alternatively from indirect sources. An example of such an indirect measurement is the use of pressure measurement in a connected residual heat removal loop or safety injection system to infer RCS pressure when the direct RCS pressure measurement is not available.

2.4.15 The procedures and guidelines developed for accident management should be supported by appropriate background documentation (e.g. technical basis document) and should be used as the basis for developing accident management programme. This documentation should describe and explain the rationale of the various parts of the guidelines. The background documentation does not replace the guidelines themselves. It should be available to all staff involved in evaluation and decision making.

2.4.16 For situations that result in normal (designated) accident management capabilities being unavailable, support procedures may be developed to provide guidance on using instrumentation and equipment to cope with these conditions (use of portable non-permanent equipment). The guidance should include conditions for use of these support procedures.

2.4.17 The guidance should contain a description of both the potential positive and negative consequences of proposed actions, including quantitative data, and should contain sufficient information for the plant staff to make appropriate decisions on the actions to be taken during the evolution of the accident.

2.4.18 In developing the procedures and guidelines, it should be considered that the information available for the operating staff or the emergency response team may be incomplete and characterized by significant uncertainties.

2.4.19 Development of accident management guidance and associated procedures should take account of the potential unavailability of instruments, lighting, power and abnormal conditions including plant state, high radiation fields, accessibility, fire etc.

2.4.20 Guidelines or procedures should be developed with the appropriate level of detail for the staff participating in accident management such as control room operators and staff involved in evaluation, decision making and implementation in accordance with their respective roles. The usability of the guidelines under stressful conditions should also be considered.

Equipment and Instrumentation

2.4.21 Availability of information on vital plant parameters in all plant states, including severe accidents should be ensured for diagnosis of the accident, monitoring the state of essential safety functions and to confirm the effectiveness of the accident management measures.

2.4.22 The equipment and instrument performance under harsh environmental conditions with reasonable assurance should be demonstrated either by equipment qualification or by assessment of the survivability.

2.4.23 For situations, such as total loss of off-site and on-site power or loss of all heat sinks or the engineering safety systems, simple alternative sources including any necessary equipment (such as mobile power, compressed air and water supplies) should be provided for accident management. Such provisions should be located at a safe place and the plant operators should be trained to use them. Refer AERB/SC/D for LWRs and PHWRs for further details.

2.4.24 Ageing and maintenance of equipment and instrumentation should be taken into account.

2.4.25 The accident management guidance should refer to the preferred accident management equipment that is available. Possible equipment failures (e.g. instrumentation failure or equipment lockout) should be considered. Alternate methods of achieving the same purpose should be explored to take into account possible equipment failures, and the availability of alternative equipment should be determined.

Organizational Aspects, Roles and Responsibilities

2.4.26 The applicant/licensee should have the full responsibility for development, implementation, evaluation and updating the accident management programme.

2.4.27 Onsite Emergency Response Organisation consisting a team of evaluators, implementers and decision makers should be available for implementing accident management strategies.

2.4.28 The roles and responsibilities of Onsite Emergency Response Organisation should be clearly defined to help ensure effective communications and decision-making for accident management. These include identification of a specialized team for performing evaluations and necessary recommendations (evaluation group), decision makers and implementers for accident management actions.

2.4.29 The decision making authority should be clearly defined and established at an appropriate level, commensurate with the complexity of the task and the potential consequences of decisions made. Major decisions which could have significant adverse effects on public safety or the environment should be made with the full knowledge of the person entrusted with legal responsibility for the plant.

2.4.30 The communication protocol that is to be followed during the implementation of accident management should be clearly defined.

2.4.31 Accident management guidance should complement, support and interact with the overall emergency arrangements defined in the plant's emergency plans and should not contradict each other. This should include lines of responsibility and accountability for implementing response actions during execution of accident management guidance throughout the duration of the accident.

2.4.32 Nuclear security measures should be maintained during all phases of accident management.

Verification and Validation

2.4.33 The developed accident management procedures and guidelines should be verified and validated.(Please see the section 3.10 for details)

Staffing and Resource

2.4.34 Adequate staff and habitability should be ensured along with clear definition of roles of the different members of the Onsite Emergency Response Organisation involved in accident management.

2.4.35 Availability of human and material resources should be ensured for carrying out accident management actions.

Training and Exercise

2.4.36 Appropriate levels of training should be provided to relevant plant personnel and members of the Onsite Emergency Response Organisation; the training should be commensurate with their responsibilities in the preventive and mitigatory domains as well as deciding on the transition between domains.

2.4.37 Robust training should be imparted to every organization involved in the management of a severe accident, including decision makers, evaluators, implementers and external emergency responders. These training programmes need to take a practical, learning by-doing approach, using realistic training aids, and to allow for an evaluation of their effectiveness.

2.4.38 The overall form of the guidelines and the selected level of detail should be tested in exercises. Based on the outcome of such exercises, it should be judged whether the form is appropriate and whether additional details should be included in the guidance. Exercises should provide for identification of areas for improvement.

2.4.39 Training and exercises need to include postulated severe accident conditions to ensure that operators are well prepared. The exercises should include the simulated use of actual equipment that would be deployed in the management of a severe accident.

2.4.40 The training programmes should be updated based on new operating experience and to take into account developments in science and engineering.

2.4.41 Training programmes should address the roles of the different groups and include exercises to enable assessments of the interactions between the various groups involved in accident management.

Review and Update of AMP

2.4.42 The accident management programme should be reviewed periodically (typically once in five years) in response to major lessons learned, to reflect operating experience, new results from relevant research and changes in plant configuration.

3 DEVELOPMENT AND IMPLEMENTATION OF AN ACCIDENT MANAGEMENT PROGRAMME

3.1 General Aspects

3.1.1 The following steps should be executed to set up an accident management programme:

a) Challenges (including events/event sequences) to safety functions and/or boundaries to fission product release should be identified
b) Plant vulnerabilities should be identified, considering the challenges
c) Plant capabilities under challenges to safety functions and fission product barriers should be identified, including capabilities to mitigate such challenges, both in terms of available equipment and personnel
d) Suitable accident management strategies and measures should be developed, including the use of permanent (fixed) and onsite/offsite non-permanent (portable and/or mobile) equipment and instrumentation to cope with the vulnerabilities/challenges identified
e) Accident management should implement all feasible measures that will either maintain or increase the margin to failure or that will gain time before the failure of safety functions or of barriers to a release of radioactive material
f) Supporting analyses should be performed to evaluate and confirm the adequacy of the strategies and measures developed, and
g) Procedures and guidelines to execute the strategies and measures should be developed

3.1.2 The following aspects should be considered while developing the accident management programme:

a) Supporting analysis and experiments for the development of the accident management programme
b) Necessary hardware provisions for execution of accident management strategies
c) The means of obtaining information on the plant status, and the role of instrumentation therein, including cases in which information provided by instrumentation is erroneous or normal instrumentation and control power is unavailable
d) Specification of lines of decision making, responsibility and authority in the teams that will be in charge of the execution of the accident management measures
e) Availability of personnel to execute the programme with consideration of human performance aspects
f) Integration of the accident management programme within the emergency arrangements for the plant
g) Verification and validation of procedures and guidelines (please see the section 3.10)
h) Education, training, exercises and evaluation of personnel skills
i) Possible restrictions on the accessibility of certain areas for performing local actions
j) A systematic approach to periodic evaluation and updating of the guidance and training with incorporation of new information and research insights on severe accident phenomena

3.2 Identification of Plant Vulnerabilities

3.2.1 Safety assessment should be performed to identify and consider all credible challenges resulting from individual events/combinations of events/event sequences that could cause failure of barriers against release of fission products. For external events, the safety assessment should consider identified margins to events in which the consequences can significantly worsen for small changes in the event magnitude (cliff-edge effect)[4].

3.2.2 Guidance for plant damage assessment should be part of an accident management programme. Of particular importance is the assessment of site and building structural damage resulting from external hazards.

3.2.3 Guidance should also be provided to address challenges to physical barriers and safety functions before any significant fission product release.

3.2.4 The vulnerabilities of the plant to challenging conditions should be identified. It should be investigated how specific accidents will challenge safety functions, and, if these are lost and not restored in due time, how the integrity of fission product barriers including fuel will be challenged. The possibility of being left with non-permanent (portable and/or mobile) equipment only for mitigating some challenges should be contemplated. Vulnerabilities resulting from the failure of command and control due to loss of control room or impairment of the capability to operationalise the on-site emergency response organization [Refer section 3.11] should also be addressed.[5]

3.2.5 The vulnerabilities to external hazards that can impact the use of accident management features, both permanently installed as well as non-permanent, should be identified. It should be investigated how specific external hazards can interfere with the use of accident management features.[6] The non-permanent (mobile) equipment should be located in diverse positions to the extent practicable so as to avoid common cause failures due to external hazards such as earthquakes and tsunami.

3.2.6 The behaviour of the plant during design extension conditions (including those caused by external hazards) should be well understood with identification of the phenomena that may occur together with their expected timing. The severity of these phenomena should be assessed and the analysis results should be collected and set out in a report that could serve as the technical basis for accident management.

3.2.7 The information regarding the plant behaviour in accident conditions should be obtained using appropriate analysis. Other inputs should also be used, such as the results of current research on severe accidents, operational experience including insights from other plants and engineering judgment. Consideration should be given to uncertainties in the severe accident knowledge base and the assumptions

[4] In a nuclear power plant, an instance of severely abnormal plant behaviour caused by an abrupt transition from one plant status to another following a small deviation in a plant parameter, and thus a sudden large variation in plant conditions in response to a small variation in input.

[5] Vulnerabilities could be created by loss of communication with the control room, physical damage to the control room (e.g. fire) harsh environmental conditions in the control room (radiological conditions, toxic gases, smoke) or staff injuries or even death.

[6] E.g. removing of rubble for accident management

made in models and analysis.

3.2.8 Effectiveness and adequacy of equipment and response centres (e.g. control room and/or OESC) that are shared by different units should be assessed for cases where accidents occur simultaneously in multiple units. Based on the result of such assessment, potential alternate solutions could be developed.

3.2.9 If structures, systems and components (SSCs) whose use is contemplated for accident management are shared between two or more units, an assessment should be performed whether safe shutdown state is achievable on the other unit(s).

3.3 Identification of Plant Capabilities

3.3.1 All plant capabilities available to fulfill and support safety functions and for mitigation of challenges to fission product barriers should be identified and characterized. This should include safety systems, complementary design features, additional safety systems as well as use of non-dedicated systems, unconventional line-ups and hook-up connections for non-permanent equipment located on-site or brought in from off-site. When unconventional line-ups or hookup connections are contemplated, consideration should be given to the availability of equipment (hoses, mobile or portable equipment) necessary for easy use of these capabilities and restoration of failed equipment. Availability of spare parts, lubricants, compressed air, water and fuel should be ensured.

3.3.2 Relevant information including lessons learned from past nuclear accidents as well as data from experimental activities should be considered during the identification of plant capabilities.

3.3.3 Specific consideration should be given to accidents developing when the facility is in a shutdown state.[7]

3.3.4 The capabilities of plant personnel to contribute to unconventional measures to mitigate accident challenges, including the behaviour and reliability of personnel under adverse environmental conditions (high temperature, poorly lit, high radiation) should be considered[8]. Where necessary, protective means should be provided and training should be imparted for the execution of such tasks.

3.4 Development of Accident Management Strategies

3.4.1 On the basis of the vulnerability assessment, identified plant capabilities, knowledge of accident phenomena and reactor specific accidents, accident management strategies should be developed for each individual challenge or plant vulnerability, in both the preventive and mitigatory domains.

3.4.2 In the preventive domain, strategies should be developed to preserve the safety functions viz. achieving and maintaining sub-criticality, core cooling, spent-fuel cooling and containment integrity.

3.4.3 In the mitigatory domain, strategies should be developed with the objective of:

[7]Due to maintenance activities some of the safety features may not be available.
[8] Including performance when using protective clothing and breathing devices.

a) terminating the progress of fuel degradation
b) maintaining the integrity of the reactor vessel/calandria
c) maintaining the integrity of the core catcher and confinement in the event of RPV failure
d) maintaining cooling of corium (in-vessel or ex-vessel)
e) preventing criticality in the core debris/corium
f) maintaining the integrity of the containment or any other confinement of fuel and preventing containment bypass
g) minimizing, delaying off-site releases of radioactive material
h) achieving a long term safe stable state (Severe accident safe state).

Strategies may be derived from 'accident management actions', examples of which are given in Appendix-A.

3.4.4 A systematic evaluation of the possible strategies should be conducted to confirm feasibility and effectiveness, to determine potential negative impacts and to develop prioritisation, using appropriate methods. Adverse conditions that may affect the execution of the strategy during evolution of the accident should be considered.

3.4.5 Particular consideration should be given to strategies that have both positive and negative impacts in order to provide the basis for a decision as to which strategies constitute a proper response under a given plant damage condition.[9]

3.4.6 Strategies should be prioritized taking into account plant damage status and the existing as well as anticipated challenges. The basis for the selection of priorities in accident management strategies should be documented. When prioritizing, special attention should be paid to the following:

a) timeframes and severity of challenges to the barriers against releases of radioactive material
b) availability of support functions as well as possibility of their restoration
c) plant initial operating mode, as accidents can develop in operating modes where one or more fission product barriers could already be lost at the beginning of the accident
d) adequacy of a strategy in the given domain; while some strategies can be adequate in the preventive domain, but may not be suitable in the mitigatory domain due to changing priorities.[10]

3.4.7 For strategies that rely on non-permanent equipment following an extended loss of all AC power (due to external events), steps should be taken to ensure that personnel can install and operate such equipment within the time frame necessary to avoid loss of safety functions taking into account possible adverse conditions on-site. Support items such as fuel for nonpermanent equipment should be available.

3.4.8 Accident management strategies should be developed for situations when DC power is also lost during a long-term loss of all AC power.

3.4.9 The implementation of specific mitigatory strategies should be triggered when

[9]An example is flooding the cavity, with the negative impact of possible occurrence of an ex-vessel steam explosion.

[10]For example, cooling the fuel could be first priority when the fuel is undamaged (in the preventive domain), while retaining containment integrity or limiting fission product releases could be the priority (in the mitigatory domain)

certain parameters reach their threshold values. These parameters should be selected to be indicative of plant damage conditions and challenges to fission product barriers.

3.4.10 If strategies are to be implemented within a certain time window, the possibly large uncertainties should be taken into account in identifying such a window. However, care should be exercised in order not to discard potentially useful strategies.

3.4.11 A systematic identification of the plant control and logic interlocks that need to be defeated or reset for the successful implementation of accident management strategies should be performed. The potential negative effects of such actions should be adequately characterized and documented.

3.4.12 The definition and selection of strategies applicable in the mitigatory domain should consider the potential usefulness of maintaining strategies initiated in the preventive domain. Limitations that could arise from harsh environmental and radiological conditions expected in the mitigatory domain should be taken into account.

3.4.13 Strategies which avoid or minimise the accumulation of large amounts of potentially contaminated water, including leakage from a failed containment should be preferred. Strategies for storing and handling of accumulated contaminated water should be considered in an appropriate manner.

3.5 Analysis for Development of Accident Management Programmes

3.5.1 Safety analysis should be performed:

a) for the accident scenarios expected in all significant sources of radioactive material (e.g. reactor core and spent fuel pools) in the plant
b) for the accident scenarios expected in all relevant normal operational and shutdown states including shutdown states with open reactor or open containment barriers
c) for identification of challenges to integrity of barriers and capabilities and to demonstrate the acceptability of the identified solutions to support the accident management strategies and measures. This also calls for the analysis without crediting the mitigatory measures
d) for formulation of the technical basis for development of strategies, procedures and guidelines
e) for verification and validation of procedures and guidelines (with other safety analysis tools, if available)
f) for source term and dose assessment
g) to support the decision making regarding plant upgrades
h) for arriving at the conditions required for environmental qualification and survivability of equipment/instrumentation
i) to arrive at working conditions/habitability of working places for personnel involved in the execution of the accident management actions
j) for identifying the accident scenarios for personnel training and exercise purposes
k) for multi-unit accidents, where applicable

3.5.2 Safety analysis should provide sufficient inputs for development of procedures and guidelines, in particular:

a) choice of symptoms (i.e., parameters and their values) for diagnosis and monitoring the course of the accidents (i.e. to determine the reactor core condition, state of protective barriers etc.)
b) identification of the key challenges and vulnerable plant systems and barriers
c) specification of set-points to initiate and to exit individual strategies
d) positive and negative impacts of accident management actions
e) time windows available for performing the actions
f) prioritisation and optimisation of strategies w.r.to achieving safety functions
g) evaluation of capability of systems to perform intended functions
h) expected trends in the accident progression
i) conditions for entering and exiting accident management including severe accident management domain as applicable
j) computational aids development

3.5.3 Suitable analysis methods with appropriate safety or risk metrics should be used to aid in decision making regarding plant upgrades. Consideration should be given to the fact that analysis in the field of severe accident management is usually not conservative but of best estimate analysis and does not in itself provide margins.

3.5.4 Plant specific data including plant operational parameters, plant systems configuration and performance characteristics and set-points should preferably be used for the analyses.

3.5.5 Address a sufficiently broad set of accident scenarios adequately covering potential evolutions of initiating events into design extension conditions and a comprehensive set of plant damage states. PSA Level 1 and 2 in combination with engineering judgement should be used for selection of the scenarios.

3.5.6 Selection of accident sequences should be performed in the following steps:

a) A suitable categorization approach and a set of plant damage states should be developed. A categorization scheme should result in a list of groups of accident sequences including fuel degradation and melting, calandria/reactor vessel failure and containment boundary failure and the associated severe accident phenomena[11]. The full list of plant damage states obtained from PSA should be screened for the less important plant damage states in order to identify a limited set, considering contribution to core damage frequency and ensuring that all initiators are represented;

b) One or more accident sequences for each plant damage state should be chosen considering the total contribution to core damage frequency and the ability of the chosen sequence to represent other sequences in the same plant damage state.

3.5.7 Following aspects of accident scenarios that would lead to core damage and subsequent potential challenge to fission product barriers should be taken into account[12]

a) Sequences with no operator action or inappropriate operator actions (errors of omission or errors of commission) leading to core damage

b) Availability and functionality of equipment, including instrumentation and the

[11]Many categorisation schemes are possible. Level 2 PSAs contain such categorisation schemes.
[12] Note that selection of sequences that would, without intervention, lead to core damage, is an appropriate way of accident scenarios for subsequent investigation of both preventive actions (taken before core damage) and mitigatory actions (taken after core damage)

habitability of working places under anticipated environmental conditions and

c) Potential cliff-edge effects.

3.5.8 Best estimate approach should be used for the safety analysis to support the accident management with appropriate recognition of uncertainty existing in the timing and severity of the phenomena. The computer codes that are used for accident management should be validated to the extent as far as reasonably practicable. Sensitivity analysis should be performed when computer code results are relied upon for making critical decisions and to identify cliff-edge effects.

3.6 Development of Procedures and Guidelines

General

3.6.1 Procedures (equivalent guidelines) or guidelines should be developed for preventive and mitigatory domains respectively to implement the strategies and measures for accident management. Procedures and guidelines should contain the necessary information and instructions for the responsible personnel to successfully implement the strategies, including the use of equipment, equipment limitations and cautions and benefits.

3.6.2 Procedures and guidelines should be written in a user friendly way so that they can be readily executed under high stress conditions, and should contain sufficient details to ensure the focus is on the necessary actions[13].

3.6.3 The guidelines should contain as a minimum the following elements:

a) Objectives and strategies
b) Positive effects and potential negative consequences of the actions
c) Initiation criteria
d) The time window within which the actions are to be applied (if relevant)
e) Monitoring of strategies
f) The equipment and resources (e.g. AC and DC power, water and instrument air) required
g) Identification of local actions with relevant guidance
h) Consideration of habitability for local action
i) Consideration of required personnel resources
j) Cautions and limitations
k) Transition criteria (EOP to SAMG) and exit/termination conditions
l) Assessment and monitoring of plant response

3.6.4 Procedures and guidelines that are implemented should be integrated with each other to establish a comprehensive strategy for accident management.

[13]For example, where water injection to primary heat transport system is recommended, it should be identified whether this should be initiated from dedicated source or alternate sources. Also the available line-ups to achieve the injection should be identified and guidance should be put in place to configure unconventional line-ups, where these are needed. It should be known how long water sources will be available, and what needs to be done to either replace or to restore them once they are depleted.

3.6.5 The guidance should directly identify the recommended action[14], when accident conditions require immediate attention and short term actions.The development of accident management guidance should take into account the habitability, operability and accessibility of the control room and OESC. Accessibility of other relevant areas, such as areas for local actions should also be assessed and taken into account in the development of accident management guidance.

3.6.6 Pre-calculated graphs, tables or simple formulae should be developed, where appropriate, to avoid or limit the need for complex calculations during the accident. These 'computational aids' should be included in the documentation of the guidelines. Typical list of computational aids is given in Appendix-E. Computer based aids should consider the limited battery life of self-contained computers (laptops) and the potential for loss of AC power.

3.6.7 Conditions during and following a natural disaster or an internal plant event may significantly impede and delay the ability of plant operators and others to respond and take needed actions. The potential for such delays should be considered when procedures and plans for time-sensitive operator actions are being established.

Diagnosis, Parameters and Instrumentation

3.6.8 In the preventive domain, it may be possible to diagnose the accident on the basis of an appropriate procedure and plant alarms and the guidance should be aimed at monitoring and preserving or restoring safety functions on the basis of the selected strategies. In the mitigatory domain it should not be necessary to identify the accident sequence or to follow a pre-analysed accident scenario in order to use the SAMGs correctly. The control room and OESC personnel should be able to identify the challenges to fission product barriers and different plant damage conditions based on the monitoring of plant parameters (A typical list of plant parameters is given in Appendix-B), if available.

3.6.9 While developing the accident management programme, a list of symptoms/parameters as feasible should be identified, for the defined plant damage conditions to help in deciding the suitable accident management strategies. A typical list of plant damage conditions for different reactor types is given in Appendix-C. However, in the event of difficulties in identification of defined plant damage conditions, suitable strategies should be selected based on the information available in MCR/OESC.

3.6.10 The set of procedures and guidelines should include relevant plant parameters that should be monitored and they should be referenced or linked to the criteria for initiation, throttling or termination of the various systems. Specific and measurable parameter values should be defined for the transition from the preventive domain to the mitigatory domain.

3.6.11 Procedures and guidelines should be based on directly measurable plant parameters. Where measurements are not available, parameters should be estimated by means of simple computations and/or pre-calculated graphs and/or using other available relevant parameters.

3.6.12 The guidelines should be developed in such a way that the potential for an erroneous

[14]For example, an immediate challenge to a fission product barrier, where 'immediate' means that there is no time or limited time for evaluation prior to decision making. Other example, 'immediate actions' to obtain a stable plant condition and work from there. Also such actions may be relevant before the OESC is available and operators must take action.

diagnosis of plant status is minimized. Redundant and diverse instrumentation and signals should be used preferably.

Transition and Termination of Guidelines

3.6.13 A transition point (entry criteria) from the preventive to the mitigatory domain should be set with careful consideration of timing and magnitude of subsequent challenges to fission product barriers. Typical entry criteria parameters for PHWRs, PWRs and BWRs are given in Appendix-D.

3.6.14 The possibility of transition from EOPs/severe accident preventive guidelines to SAMGs before OESC is operable should be considered in the development of procedures and guidelines.[15] Any mitigatory guidance provided to control room operators in this case should be presented in a way that makes prompt and easy execution possible and, therefore should be presented in a format operators are able to work with and already trained for.

3.6.15 In addition to entry conditions to the SAMGs, exit conditions and criteria for terminating long term provisions should be specified. Typical exit conditions are also specified in Appendix-D. Safe state or severe accident safe state as applicable should be clearly defined and provisions to maintain these states should be specified.

3.6.16 Where EOPs are not exited but are executed in parallel with the SAMGs, their applicability and validity in the mitigatory domain should be demonstrated. In such cases, a hierarchy between EOP and SAMG actions should be established, in order to address conflict, if any.

3.6.17 Guidance should include the rules of usage for parallel execution of EOPs and guidelines and parallel execution of two different guidelines. Priorities should also be defined among the various procedures and guidelines, in accordance with the priority of the underlying strategies.

Equipment

3.6.18 It should be noted that various equipment may start automatically or change configuration upon certain parameters reaching pre-defined values (‘set points’). Such automatic starts have usually been designed for events in the preventive domain. These automatic actions may be counterproductive in the mitigatory domain. Hence, all automatic actions should be reviewed for their impact in the mitigatory domain and, where appropriate, equipment should be inhibited from automatic start. These aspects should be included in the guidelines along with a caution note indicating their positive and negative effects. Manual start of the equipment concerned should then be considered in the guidance.

3.6.19 Guidance should be developed to diagnose equipment failure and to identify methods to restore failed equipment to service. The guidance should include recommendations on the priorities for restoration actions.

3.6.20 The time to recover unavailable equipment or to implement/connect non-permanent equipment should be factored into accident management guidance.

[15] This situation can occur in cases where an event rapidly develops into a severe accident, or where the OESC cannot be activated within the time assumed in the guidance.

Multi-unit Damage

3.6.21 The guidelines should address the possibility that more than one, or all units, may be affected, including the possibility that damage propagates from one unit to other(s), or is caused by actions taken at one unit.

3.6.22 Guidelines should also cover events with multi-unit damage, potential damage to the fuel in spent fuel pools, release of radioactivity and hydrogen into buildings adjacent to the containment, if applicable, and run off of contaminated water to the environment.

3.6.23 Multi-unit damage or large-scale external disturbances may impact the time required in restoring the power and the human and organizational performance. Hence long time periods should be considered in the guidelines for initiation and completion of the required actions.

3.6.24 Guidance for the assessment of damage to the plant should be part of the accident management programme and should be developed to address challenges to the fundamental safety functions or the fission product barriers before any significant fission product release. Of particular importance is the assessment of access to the site and structural damage to buildings resulting from external hazards more severe than those considered for design, derived from the site hazard evaluation

Documentation

3.6.25 Adequate background material should be prepared to support development of accident management guidelines. The background material should fulfill the following roles:

a) It should be a self-contained source of reference for:

   (i) The technical basis for strategies and deviations from generic strategies, if any

   (ii) A detailed description of instrumentation needs

   (iii) Results of supporting analysis

   (iv) The basis and detailed description of steps in procedures and guidelines

   (v) The basis for specification of set-points used in the guidelines

b) It should provide basic material for training courses for accident management staff.

Additional Guidance for Spent Fuel Accident Management

3.6.26 Failures of the cooling system, make-up water system, loss of pool water caused by pipe breaks and the siphon phenomenon, where water level cannot be maintained as applicable should be assumed. Loss of systems concurrently with fires and explosions should be assumed while developing the guidelines.

3.6.27 Countermeasures and documented procedures should be established to prevent fuel damage (maintaining a sufficient water level for cooling and shielding and also adequate boron levels for sub-criticality if envisaged).

3.6.28 The possibility of damage to the SFP structure leading to leakage larger than compensatory provisions (make-up system) should be considered. Leakage could be mitigated by the provision of sealing systems designed to provide temporary repair to breaches, or to minimise the leakage rate to levels within the capability of the make-up system.

3.6.29 For enhancing reliability of cooling of SFPs, water source requirements should consider conservative decay heat loads.

3.6.30 Addition of water from mobile sources (such as fire tender or fire engine) or fire protection systems should be considered as a back-up for water injection with consideration for possible boron dilution if any. To minimize the addition of boric acid, fuel storage racks maybe designed with neutron absorbing materials in the structure.

3.6.31 Reliable means of monitoring water level, temperature and radiation/activity levels of the SFP should be established. It is also desirable to monitor states of SFPs through video cameras. The instrumentation should be provided with alternative power sources to ensure its availability in all accident conditions.

3.7 Hardware Provisions/Instrumentation for Accident Management

Hardware Provisions for Accident Management

3.7.1 Reactors should be equipped with hardware provisions (which may include supplementary onsite and offsite equipment) to fulfill safety functions viz. to maintain sub-critical, decay heat removal and containing the release of fission products for all accident conditions including severe accidents.

3.7.2 Appropriate provisions should be available to remove the decay heat from the core/corium debris/spent fuel pool to an ultimate heat sink.

3.7.3 Equipment Upgrades[16]/Changes in Design

a) Changes in design should be evaluated where challenges to fission product barriers cannot be reduced to an acceptable level.

b) Equipment upgrades aimed at enhancing preventive features of the plant and preserving the containment function should be considered as tasks with high priority.

c) Equipment upgrades which increase capability or margin to failure for the following functions should be taken into account:

(i) Monitoring key parameters such as temperature, pressure, radiation level, hydrogen concentration and water level (containment/calandria vault/calandria etc.)

(ii) Containment isolation in a severe accident, including prevention of containment bypass

(iii) Ensuring the leak-tightness of the containment, including preservation of the functionality of isolation devices, penetrations, personnel locks etc., for a reasonable time after a severe accident

(iv) Establishing or restoring the containment heat sink to manage pressure and temperature in the containment

(v) Control of combustible gases, fission products and other materials released during severe accidents

(vi) Monitoring and control of containment leakages and of fission product

[16]Refer clause 3.5.3 for analysis methods and corresponding risk metrics in decision making w.r.to plant upgrades

releases

(vii) Prevention and mitigation of dominant challenges, such as for containment over-pressure and under-pressure, high-pressure core-melt scenarios, reactor vessel/calandria vessel melt-through and basemat melt-through by molten corium.

3.7.4 There should be multiple diverse accident management strategies and measures for mitigating challenges to containment integrity.

3.7.5 For non-permanent equipment, multiple hook-up points to facilitate their use during external hazards should be considered, taking into account benefits versus potential negative implications.

3.7.6 When additional equipment is supplemented to mitigate severe accidents, it should preferably be independent with equipment and systems used to cope with design basis accidents.

3.7.7 Containment Venting

a) the accident management programme should provide guidance on containment venting, if envisaged as a last resort, to prevent loss of containment integrity and to mitigate releases of radionuclides causing long-term off-site contamination.

b) When containment venting is contemplated or directed in the accident management strategies, it is recommended to consider the following in the guidance:

   (i) situations when all AC and DC power is lost and the instrument air system is not available

   (ii) situations involving high radiation areas and high temperatures in areas where vent valves are located (if local access is required)

   (iii) the potential negative consequences of containment venting should be assessed during the decision making process

3.7.8 Guidance should consider additional hardware provisions, including non-permanent on and off-site equipment as a back-up measure where the existing equipment is not anticipated to remain functional in the long-term or could be disabled in case of station black-out. In estimating the long-term availability of components, the feasibility of performing maintenance or repairs should be evaluated and taken into account.

3.7.9 Steps should be taken to ensure that personnel can install and operate the non-permanent equipment within the timeframes necessary taking into account possible adverse conditions (radiological conditions, lighting, ventilation, temperature etc.).

3.7.10 Maintenance, testing and inspection procedures should be developed for equipment to be used in accident management taking into account the safety significance of such equipment.

Instrumentation for Accident Management

3.7.11 Adequate instrumentation for the monitoring and diagnosis of reactor conditions and for assisting in accident evaluation, accident management decision-making and execution of actions at each stage of the accident progression should be available. Instrumentation should provide data to support the operator actions and to monitor the effectiveness of accident management actions. Adequate instrumentation should also be provided for entry and exit criteria used in accident management. Typical parameters that are used in accident management programme are given in Appendix-B.

3.7.12 Essential instrumentation needed for monitoring core, containment and spent fuel conditions should be identified. These monitoring functions should be maintained throughout an extended SBO. A list of instrumentation for each stage of the accident progression for obtaining the necessary information on key parameters such as neutron flux, temperature, pressure, flow, water level, combustible gas concentration and radiation level should be established. In case of unavailability of direct parameter monitoring, indirect parameters can be co-related and may be made use of. Use of portable instrumentation may be considered in the accident management programme.

3.7.13 Guidance should be provided to validate important instrumentation outputs (i.e., those used for symptom based diagnosis of potential challenges to fission product barriers or for confirmation of the effectiveness of implemented strategies). All important instrumentation readings should be verified with other independent information[17,18] where possible. This should also be emphasized in exercises.

3.7.14 The time needed for obtaining adequate information from plant parameters important for accident management should be taken into account when developing guidelines.

3.7.15 It should be confirmed that information needed for decision making during execution of accident management strategies can be obtained from the instrumentation in the plant. Such information should be available in multiple places viz. main and supplementary (if available) control rooms and OESC where the evaluation and decision making are to be made.

3.7.16 The uncertainty of readings of instruments essential for accident management should be assessed and appropriately considered.

Survivability of Equipment and Instrumentation

3.7.17 When adding or upgrading equipment/ instrumentation for design extension conditions with out and with core melt, the equipment or instrumentation is expected to operate under harsh environmental conditions (high temperature, high pressure, high radiation level, high concentration of combustible gases, seismic acceleration, moisture and corrosive environments, debris in the environment, wind-blown missiles and submergence). The equipment and instrument performance under harsh environmental conditions with reasonable assurance should be demonstrated either by equipment qualification or by assessment of the survivability. The instrument readings may have some inaccuracies in the harsh environment but it should be within acceptable range to monitor the parameter with reasonable assurance.

3.7.18 Environmental conditions expected during accident conditions should be determined using appropriate accident simulations which models the accident progression. These simulations should also help to determine the necessary instrument ranges (including margins), instrument mission times and anticipated environmental conditions including uncertainties.

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[17] Instruments may continue to provide information, such as trends, even if the readings are not accurate.

[18] For examples, sometimes, a degree of malfunction of thermocouples depends on temperature, humidity, salt deposition and other environmental factors.

3.7.19 Survivability of the equipment/instrumentation that could be used in SAM should be evaluated through a systematic review and assessment of equipment/instrumentation functions and conditions based on the available knowledge and data, such as from equipment environmental qualification for DBA, severe accident testing and analysis, and engineering judgment. The following steps should be considered for assessment of survivability:

a) identification of accident management actions for mitigating severe accidents

b) definition of fuel and core damage stage (plant damage conditions) and time period for each accident management action

c) identification of equipment and instrumentation designated to perform each of the actions

d) determination of the bounding environmental conditions expected for this equipment and instrumentation within each time period.

e) cumulative environmental effects should be considered including passive and active phases.

f) Capability demonstration that the equipment will survive to perform its function

3.8 Personnel Staffing and Needs

3.8.1 Persons with designated roles and responsibilities who will be part of the accident management should be identified. This should take into account of accidents developing over a long period so that adequate shift manning is always maintained.

3.8.2 Adequate staffing levels and personnel qualifications should be established for implementation of accident management measures taking into account the possibility that multiple units can be affected simultaneously and taking into account the requirements for emergency response. Staffing should be capable of sustaining an adequate response until relief arrives when the plant is isolated for some time.

3.8.3 Acceptable working conditions (habitability) should be provided to plant and external support personnel in situations where the site is partially or totally isolated from continuous off-site support.

3.8.4 The shift change over document should contain at least severe accident related information such as the severe accident sequence development, the procedures and guidelines in use at the time of the transition from the preventive to the mitigatory domain, the emergency teams involved in the mitigation, possible instrumentation inaccuracies and the recovery actions undertaken for unavailable systems. During turnovers, the new shifts should be provided with the accident-related information as well as other information deemed appropriate to maintain continuity in strategies for managing the accident.

3.8.5 Contingency plans should be developed for situations where accident management staff have been incapacitated or when outside support may be delayed.

3.8.6 Contingency plans, training and guidance should be developed to help personnel cope with the emotional stress affecting personnel performance during a natural disaster or nuclear accident.

3.9 Organizational Aspects, Responsibilities and Interfaces with Emergency Preparedness and Response

Roles and Responsibilities

3.9.1 The Onsite Emergency Response Organisation typically carries out the functions as depicted in Figure 3.

On-site Emergency Response Organisation

Accident management:
Performing functions to manage the accident at the plant. This includes evaluations, recommendations, implementation and necessary decision making.

Emergency Response:

i. Assessment of the emergency arising from the plant conditions and declaration of appropriate emergency classification.

ii. Onsite response: fire, medical, communication, survey, rescue, security, transport etc.

iii. Provides recommendations/guidance to the 'Responders', having mandated responsibility for implementation of the emergency plans in the public domain

Dose assessment and determination/recommendation of response actions (on-site and off-site) based on plant conditions.

Figure 3: Typical functions of on-site emergency response organization

3.9.2 Roles of personnel involved in accident management should be clearly defined and documented, including:

a) Evaluators: The role of evaluators is to assess the plant conditions, identification of potential actions, evaluation of the potential impacts of these actions and recommendation of actions to be taken, assessing the outcome of actions after implementation and dose assessment in support of accident management actions.

b) Decision Makers: The role of decision makers is to approve the recommended action or deciding other appropriate actions for implementation.

c) Implementers: The role of implementers is to operate the equipment as necessary including verification of operation. This includes remote operations from the control room and also local actions by appropriate personnel to recover or connect equipment.

The elements, roles and responsibilities of personnel involved in accident management are depicted in Figure 4.

Accident Management

Evaluation and Recommendation	Decision Making	Implementation
Plant Assessment: a) Evaluate plant symptoms b) Determine plant conditions c) Review status of equipment recovery d) Identify and prioritise strategies for accident management e) Assess positive and negative aspects of strategies f) Recommend implementation of strategies and actions g) Monitor safety function status, plant response to actions and for exit conditions **Radiological Assessment**: a) Dose monitoring and assessment	a) Authorize strategy implementation b) Make informed decisions on on-site actions (e.g. containment venting) that may impact off-site emergency activities c) Determination/recommendation of off-site actions (if any) d) Evaluate offsite consequences of recommended actions (if applicable)	**MCR/Field Actions/Damage Control**: a) Perform immediate actions b) Implement new strategies and actions c) Ensure ongoing strategies can be continued d) Implement actions to recover failed equipment **Emergency Response:** Rapid response team (fire, medical, rescue), Survey teams, Communications team, Security, etc.

Figure 4: Elements, roles and responsibilities of the personnel involved in accident management

3.9.3 The decision making authority should lie with the emergency director/advisory group in both preventive and mitigatory domains. Until the emergency director/advisory group takes charge, the control room staff should continue to make necessary decisions.

3.9.4 The emergency director should be granted the authority to decide on the implementation of accident management measures proposed by the plant evaluation group or, when necessary, based on his own judgment. The emergency director should maintain a broad understanding of the actual status of the plant, plant capabilities and vulnerabilities and key accident management actions, including their off-site effects. The emergency director should have the authority to take any necessary actions to mitigate the event including venting containment or injecting low quality water into the reactor without the need for external authorization.

3.9.5 Responsibilities and authorities for implementation of certain accident management actions with a potentially significant impact[19] should be established in the on-site emergency response organization.

3.9.6 Contingency, where a certain authority level is incapacitated should be addressed in the accident management programme[20]. This should identify an alternative authority and decision maker.

3.9.7 When external support to accident management is contemplated, responsibilities, priorities and contingencies should be addressed in a way that minimizes the possibility of negative interaction between activities performed by site personnel and external support teams. Accident management should be implemented to ensure that all teams have a common situational awareness.

Transfer of Responsibility and Authority

3.9.8 The points at which authority for decision-making and implementation of accident management actions is transferred should be clearly established.

3.9.9 When transferring responsibilities and decision making authority, impact of external hazards should be considered, in particular, when placing the decision making authority for accident management at both on-site and off-site locations. Guidance should be also provided for the case of failure of the communication network.

3.9.10 In transferring the overall authority for accident management from the control room to the emergency director, the functions that remain in the control room and actions that can be decided upon by the control room staff independently of the emergency director should be specified.[21] As the control room staff is also responsible for the execution of the measures decided upon by the emergency director, consistency, and a hierarchy, between the two groups of actions should be established.

3.9.11 The transfer of responsibility and authority should not create a ‘vacuum’ in decision making and necessary actions. Hence, formal transfer should not take place until the new decision maker is ready to assume his/her role. Transfer of responsibilities and authorities should be consistent with the emergency plan.

Onsite Emergency Support Centre

3.9.12 Personnel working in OESC should have a detailed knowledge of the procedures and guidelines. They should have prompt access to the information on the plant status and understanding of the underlying accident phenomena.

3.9.13 Criteria for activation of the OESC should be unambiguous, clearly specified in plant procedures and/or on-site emergency plan. Accident management measures should continue to be decided and carried out from control room until OESC is operational. When there are multiple support teams, their responsibilities and interfaces should be defined.

3.9.14 Depending on the situation, the OESC may be activated in the preventive domain and

[19]For example, containment venting or use of un-borated water for injection to a PWR core and/or spent fuel pool (SFP)

[20]Incapacitation could be the result of site isolation.

[21]These include activities that control room staff can carry out independently, such as maintaining support conditions (e.g. room cooling, service water) and responding to some alarms; activities that the control room staff should not do on their own (e.g. starting up major equipment) should also be specified.

the Onsite Emergency Response Organisation should provide technical support to the control room staff as necessary.

3.9.15 Support from qualified organizations, including the plant vendor or designer, should be sought, if required, for evaluation and recommendation of appropriate accident management measures. The mechanisms for calling on early support should be established.

3.9.16 The mechanisms for ensuring the flow of information between the OESC and the control room as well as from the OESC to other parts of the emergency response organization, including those responsible for the execution of on-site and off-site emergency plans, should be specified. As the occurrence of a severe accident will generate extensive communication between on-site and off-site teams, care should be taken that this communication does not disrupt the management of the accident at the plant.

3.9.17 Information about the performance of the instrumentation and equipment required for accident management should be made available to the OESC. Preferably the OESC should have direct access to plant information required for accident management. The availability and use of such information should be considered in the development of guidelines. The plant information in the OESC should be recorded and monitored appropriately.

3.9.18 Extended loss of AC power should be considered in providing for communication between the control room, the OESC and off-site facilities.

Interfaces with Emergency Preparedness and Response

3.9.19 Appropriate interfaces between the accident management programme and the emergency plan should be established for an effective response to emergencies (including nuclear or radiological emergencies, both on-site and off-site).

3.9.20 A review of the emergency plan and accident management programme should be performed with respect to the actions that should be taken according to the emergency response plan and accident management strategy, to ensure that conflicts do not exist.

3.9.21 Use of the AMGs must interface with the organizational structure and actions defined in the emergency plan to ensure a consistent and coordinated response to accident conditions.

3.9.22 For multi-unit sites, the site emergency plan should include the necessary interfaces between the various parts of the overall emergency response organization. Plant emergency director should decide on the appropriate actions at that unit. An overall emergency director (site emergency director) should also be assigned to coordinate activities and priorities amongst all affected units on the site. Decision making responsibilities should be clearly defined. In case of different operating organizations at a given site, appropriate mechanism should be established on coordination of emergency response activities including accident management guidance.

Communication Interfaces

3.9.23 Reliable communication network between the different locations of the emergency response organization should be used. Guidance should be put in place for measures to be taken if off-site communication fails and only the on-site emergency response organization remains functional. The effects of a station black out on the communication equipment should be considered.

Management System

3.9.24 The operating organization should integrate all the elements of the accident management programme within the existing management system so that processes and activities that may affect safety are established and conducted coherently for the protection of site personnel, the public, and the environment.

Quality Assurance Aspects of the AMP

3.9.25 The background documentation should provide a demonstration of compliance with the relevant quality assurance requirements.

3.9.26 Operators should develop a programme for update and administrative control of procedures and guidelines to take into account of changes that would be required because of enhancements arising due to operating experience or due to any other reason.

3.9.27 Where modifications to procedures and guidelines are needed, it should be necessary to determine the process for their implementation. Changes to documents should be reviewed and recorded and should be subjected to the same level of approval as the documents themselves.

3.9.28 The general process for administrative control of procedures should be well established in NPPs. In general, the following should be considered when modifications to procedures and guidelines are needed:

(i) changes should be verified

(ii) changes should be validated in agreement with their significance. Some very small changes may not need validation, but the cumulative effect of many small changes included in one revision or in different revisions should be taken into account

(iii) old documents (e.g. procedures, guidelines, background documentation) should be replaced with the revised documents in all the appropriate locations (control room, onsite emergency support centre, etc.)

(iv) personnel should be trained on the new procedures and guidelines

3.10 Verification and Validation

3.10.1 The verification process should confirm the compatibility of instructions given in the procedures and guidelines with referenced equipment, user-aids and supplies (e.g., non-permanent equipment, job aids, strategy evaluation materials, etc.). It should also confirm the correctness of a written procedure or guideline and ensure that technical and human factors have been properly incorporated. The review of plant specific procedures and guidelines in the development phase, in accordance with the quality assurance regulations, forms part of this verification process.

3.10.2 The consistency of procedures and guidelines should be checked for the written correctness with the documents such as plant-specific writer’s guide. For example, text is readable with no typographical errors and that information is consistently organised and presented.

3.10.3 The technical accuracy of verification involves checking of consistency of procedures and guidelines with the background documents. Typically, the following should be performed for the assessment of technical accuracy:

a) check the entry conditions, symptoms or states for correctness
b) identify and confirm sequences, steps, warnings and notes from source documents
c) ensure that specified values (quantitative information) are correct, plant specific, margins are included and computed accurately. Also ensure that this information is adequate for the operator
d) checking plant hardware information to ensure that the instrumentation exists at the plant, and that the instrument is available during accident conditions' delineations

3.10.4 The goal of validation is to ensure that the procedures and guidelines are usable and correct. The level of detail in the procedures and guidelines should be checked for its sufficiency and ease of understanding.

3.10.5 It should be checked that the procedures and guidelines are compatible with plant responses, systems/instrumentation, shift manpower and control room/OESC information to ensure that the operator is able to complete the required action with the hardware and systems that are in place.

3.10.6 It should be checked whether shift manpower is adequate to comply with the actions specified within the procedures and guidelines and whether policies for operator duties and responsibilities conflict with actions specified in the procedures and guidelines. It should also be evaluated whether time critical actions can be performed with the current shift and in the allotted time and whether the operating crews can follow the sequence of actions.

3.10.7 Validation of the procedures and guidelines should be performed by the most appropriate or a combination of the following methods:

a) control room personnel performing the actions according to scenarios using the full scope simulator
b) an engineering simulator or other plant analyser tool
c) the walk-through method, whereby personnel should conduct a step-by-step enactment of their actions without carrying out the actual control functions
d) the table-top validation method, whereby personnel explain and/or discuss steps of the procedure in response to a scenario. The table-top method may be used where access to plant equipment is not practical
e) exercises

3.10.8 The evaluation process and acceptance criteria for SAMGs validation should address issues related to the following topics during observation or participation in the validation exercises:

a) interfaces between EOPs, SAMGs and other guidelines: clarity of transfer points, appropriateness of timing, clarity of responsibilities during transitions;
b) control room guidelines: availability of necessary plant parameters, logical order of decision steps, missing or extraneous steps, ability to accomplish steps, clear and understandable instructions, communication considerations;

c) OESC diagnostics: availability of necessary plant parameters, usability of computational aids, appropriateness of parameters for plant conditions and threats, logical order of diagnostic priorities, missing or extraneous steps, ability to accomplish steps, timeliness of diagnostics cycle;
d) OESC guidelines: availability of necessary plant parameters from the control room, logical order of decision steps, missing or extraneous steps, ability to accomplish steps, applicability of SAMG strategies, clear and understandable instructions, adequate consideration of negative impacts, clarity of SAMG decision-making process, usability and scope of computational aids;
e) SAMG - emergency plan interface: conflicts of actions and priorities between the emergency plan and SAMGs for particular plant conditions, clarity of responsibilities for each SAMG step/action, coverage of guidance after exiting SAMGs.

3.10.9 Validation tests should address the organizational aspects of accident management, especially the roles of the evaluators and decision makers, including the staff in the control room and OESC.

3.10.10 Changes made to guidelines and procedures should be re-evaluated and re-validated, to maintain the adequacy of the accident management programme.

3.10.11 Validation should be performed in a way that realistically simulate the conditions present during an emergency and include simulation of other response actions, hazardous work conditions, time constraints and stress. Special attention should be paid to the use of portable and mobile equipment, when such use is contemplated. This should also include needed local actions, contingencies, and its proper connection to plant equipment, multi-unit events, emergency lighting, etc., and the time needed for these actions.

3.10.12 All equipment identified in the accident management programme, including nonpermanent equipment, should be tested to verify that performance conforms to the requirements[22]. Testing should include the equipment and the assembled sub-system needed to meet the planned performance.

3.10.13 A cross-functional safety review of the plant should be performed with the objective of fully understanding all accident management implications. This review should incorporate a plant walk-down for assessing which kind of difficulties could exist for practical implementation of accident management measures, in particular in case of an external hazard.

3.10.14 Staff involved in the validation of the procedures and guidelines should be different from those who developed the procedures and guidelines. Developers/Writers of plant specific procedures and guidelines should prepare appropriate validation scenarios and should participate as observers to the validation process.

3.10.15 The findings and insights from the verification and validation processes should be documented and used for providing feedback to the developers of procedures and

[22] Environmental conditions including temperature, pressure, humidity, radiation and chemicals will vary greatly with the time and location so that the equipment important to safety must be established for the most severe design basis accident.

guidelines for any necessary updates before the documents are brought into force by the management of the operating organization. The documentation should be stored safely in order to provide for any future revalidation.

3.11 Accident Management Training and Exercises

3.11.1 Personnel responsible for performing accident management duties should be trained to acquire the required knowledge, skills, and proficiency to execute their roles. A comprehensive training programme for accident management should be prepared. Training should include a combination of education (classroom training) and exercises, supported by appropriate means, such as desktop training or adequate simulation tools.

3.11.2 The decision makers should be trained for understanding the consequences and uncertainties inherent in their decisions; the implementers should ensure that they understand the actions that they may be asked to take; and the evaluators should ensure that they understand the technical basis upon which they will base their recommendations.

3.11.3 Training should be developed using a systematic approach to training. This includes identifying training needs, defining the training objectives, identifying the technical basis for training material, developing training material and measuring the effectiveness of training to provide feedback to the training process.

3.11.4 Training should be established and implemented for each on-site group and external support group involved in accident management. Training should be commensurate with the tasks and responsibilities of the participants, taking into account appropriate technical level needed for each group. In-depth training should be contemplated for people entrusted with critical functions in the accident management program.

3.11.5 Training material should be developed by subject matter experts and qualified trainers. Further, experts could assist in answering questions that are beyond the capability of professional trainers.

3.11.6 Training, including periodic exercises should be sufficiently realistic[23] and challenging to prepare personnel responsible for accident management duties to cope with and respond to situations expected to occur during an event[24], including accidents occurring simultaneously on more than one unit, from different reactor operating states and in the spent fuel pool. Training should consider unconventional line-ups of the plant equipment, use of non-permanent equipment (such as diesels or pumps) as well as repair of the equipment. Training material should address implementation of strategies under adverse environmental conditions, including those resulting from external hazards, under potentially high radiation situations and under influence of stress on the anticipated human behavior.

3.11.7 Initial training as well as refresher training should be developed for all groups involved in accident management. The frequency of refresher training should be established

[23]Exercises should extend over a time period long enough not to unacceptably distort plant response, and allow to test transmission of information during shift changes.
[24]Special exercises should be developed to practice operating shifts and OESC personnel changeover and information transfer between different teams

based on the difficulty and importance of accident management tasks. The interval for refresher training should be defined based on the outcome of exercises held at the plant. Changes in the guidance and/or use of the guidance should be reflected in the training programme.

3.11.8 Exercises should be based on scenarios that require application of a substantial portion of the overall accident management programme along with emergency response. Large scale exercises providing an opportunity to observe and evaluate all aspects of accident management should be undertaken.

3.11.9 Accident management exercises should be performed periodically by considering the unavailability of information sources, equipment and facilities that potentially could be damaged in the accident.

3.11.10 Criteria for evaluating the effectiveness of an exercise should be established. Such criteria should characterize the ability of the team participating in the exercise to understand and follow the evolution of plant status, to reach sound decisions (including unanticipated events) and initiate well-founded actions, meet job performance criteria and exercise objectives.

3.11.11 Some of the scenarios used for exercises should consider core damage state, failure of the reactor pressure vessel/calandria and containment.

3.11.12 Attention should be paid to exercises that enhance the awareness of control room personnel, OESC personnel on the need of overriding controls and interlocks along with their possible consequences for implementing some successful strategies.

3.11.13 Results from exercises should be systematically evaluated to provide feedback for training programme, procedures, guidelines and organizational aspects of accident management.

3.12 Updating Accident Management Programme

3.12.1 The accident management programme (background documentation, accident management strategies, provisions, procedures and guidelines) should be updated as and when new information becomes available. This may include the potential for new accident scenarios, state-of-the art knowledge, experimental data obtained from severe accident research programmes and lessons learned from the accidents, phenomena or challenges to physical barriers, or any other significant effect on accident management that had not been fully considered previously. PSA revisions which identify the new accident sequences or changes in weightage of existing sequences, that were not part of the basis of the existing accident management guidance should also considered in updating the accident management programme.

3.12.2 The effect of any changes in the plant design including the available non-permanent equipment or the operating organization on the accident management programme should be evaluated. A formal process should be developed for updating the accident management program when such changes are implemented.

3.12.3 The accident management procedures and guidelines that are based on a reference design or some other generic source of information, should be updated when the originator of the procedures and guidelines on the reference design issues a revision of the accident management programme.

3.12.4 When the new information challenges the basis of current external event design assumptions, the capability of installed equipment and accident management procedures and guidelines should be evaluated to determine if safety functions could be compromised. Based on this evaluation, measures for updating the accident management programme commensurate with the impact should be identified.

3.12.5 Strategies should be documented and maintained, including those for using non-permanent equipment and including the technical background. Changes to the documentation should contain a record of previous strategies along with the basis.

3.12.6 Any update of the accident management programme should include revision of background documents including supporting analysis, as applicable used for their implementation and training documentation.

4 EXECUTION OF PROCEDURES AND GUIDELINES

4.1 In case of an emergency, in particular, one taking place in combination with an external hazard, plant staff should assess the global situation on-site and ensure that their emergency command and control structures (roles, responsibilities and authorities) are capable of directing responses in accordance with established procedure and guideline sets. If required, contingencies developed to re-establish command and control should be implemented.

4.2 The assessment of the situation should include:

a) number of affected units

b) control facilities functionality and habitability

c) damage to essential structures and buildings

d) availability of access to essential buildings and equipment and

e) capability to communicate with off-site organisations.

4.3 Once the control room staff, while executing the EOPs, has reached the point of entry to the SAMG domain, the transition from the EOP domain to the SAMG domain should be made.

4.4 The control room staff should initiate actions under the SAMGs that apply until responsibility for recommending actions is transferred to OESC and till emergency response team takes over. This occurs when the OESC is operable, is informed about the overall situation, has evaluated the plant status and is ready to give its first recommendation or decision on execution of a SAMG. The control room staff should continue to work with actions already initiated in the EOP domain provided they are consistent with the rules of usage of the SAMG. The conflicts between EOP and SAMG should be taken into account during execution.

4.5 The OESC should reassess plant conditions at regular intervals as the accident progresses, to confirm or adjust the priorities for mitigatory actions.

4.6 Recommendations should be presented by the OESC evaluation personnel preferably in written form to the decision maker, who will decide on the course of actions to be taken.

4.7 Decisions on actions to be taken should be given to the control room staff in an unambiguous manner that minimises misunderstandings. The main control room staff should confirm the actions that were directed and should promptly report back the progress and impact of these actions. Oral (telephone) communication to the control room staff should preferably be carried out by OESC personnel who is a licensed operator.

4.8 The key plant parameters should be displayed in an easily accessible way, e.g. by optical means (displays) or by wall boards. Long term station blackout should not lead to loss of data. Trends should be noted and recorded. Actions taken should also be recorded. Other relevant information, such as the EOP or SAMG applicable at the time, emergency alerts for the plant and planned releases of radioactive material should also be recorded. Adequate technical means should be available for this.

4.9 The timing and magnitude of possible future releases as a consequence of accident management guideline actions or their failure should be estimated at regular intervals, and should be communicated in a suitable form through proper channels to the organization responsible for further actions.

4.10 The work at the OESC should be well structured and based on a clear task description for each staff member. The OESC personnel should convene in sessions at regular times and should leave sufficient time for individual staff members to do their analysis between these regular sessions.

4.11 The OESC personnel should ensure that external organisations are aware of planned actions with potential impact on the plant surroundings. Through consultations it should be ensured that off-site response organizations are aware of and prepared for planned releases. Alternatively, the releases should be delayed to a later time, if such a shift is compatible with the accident management actions foreseen. Final decision making rests with the person at the highest level in the Emergency Response Organisation.

4.12 A mechanism should be put in place to assign priorities in case of a conflict between planned releases and the off-site readiness. In principle, priority should be assigned to the actions that prevent major damage to the fission product barrier still intact.

4.13 The process for decision making should take into account the fact that decisions may have to be made in a very short time frame. A basic principle is that the decision making process should always be commensurate with the time frame of the evolution of the accident.

5 DOCUMENTATION OF ACCIDENT MANAGEMENT PROGRAMME

5.1 Aspects of accident management should be described by a set of accident management documents consisting of procedures, guidelines together with their technical basis and supporting safety analysis reports for justifications, explanations, verification and validation. There are also other related documents such as description of the reactor physical protection, PSA studies, equipment and instrumentation survivability assessments and reactor evaluation reports (e.g. stress test)that should be available as appropriate.

As a minimum, the licensee should have the following documented information:

- goals and principles used for development and implementation of the accident management
- technical basis and results of probabilistic and deterministic analyses conducted in support of accident management
- EOPs/equivalent procedures or guidelines and SAMGs performance capabilities for the systems and equipment that are used in support of accident management procedures and actions
- list of plant parameters that are used in accident management programme
- responsibilities of persons and organizations involved in accident management, including requirements and plans for personnel training
- results of the accident management validation and reviews
- equipment and instrumentation survivability assessments

The technical basis documents provide technical information important to the identified accident management measures. They can build-on or provide a cross-reference to the existing technical descriptions. They should include, but not be limited to:

- justification for selection of accident scenarios and coverage, including a general description of reactor response to accidents
- distinct stages of an accident progression if no accident management actions are credited
- understanding of phenomena and the associated physical processes, including challenges to fission product barriers and the associated mechanisms and conditions
- state of the current knowledge of the phenomena, including current predictive capabilities for modelling the phenomena and physical processes and analytical and experimental supports
- any other special topics or important aspects for the development and verification of EOP and SAMG

Reviews and revisions of the accident management documents should be tracked and controlled.

APPENDIX-A: ACCIDENT MANAGEMENT ACTIONS

The following is a typical list of accident management actions in response to the plant damage conditions as applicable:

a) Inject water into the primary system/RCP seal/calandria vessel/calandria vault/End Shield
b) Inject water into the containment
c) Containment sump/core catcher cooling
d) External cooling of RPV
e) Injection of water into the SGs/Boilers/Decay Heat Removal System
f) Spray within the RPV (BWR)
g) Spray into the containment
h) Injection of water to spent fuel pool
i) Restart RCPs
j) Depressurize the RPV (reliable depressurisation of the RCS in order to prevent high-pressure core melt)
k) Depressurize the SGs
l) Isolate the Containment
m) Operate containment coolers
n) Control of the concentration of hydrogen and other flammable gases
o) Operation of igniters
p) Inert the containment with non-condensables (BWRs)
q) Steam inerting of the containment
r) Vent the containment
s) Establishment and maintenance of reactivity control in the reactor and in the spent fuel pool.
t) Minimise the unfiltered releases of radioactive products

The actual list should depend on the plant's characteristics and actual application will vary from plant to plant. Both the positive and negative consequences of these actions should be considered. This should be done for each plant damage condition to which these actions are applied or for each of the guidelines that have been derived from these actions.

The following are the examples of positive and negative effects of some of the accident management actions mentioned above:

a) Inject water into the RCS

Positive effects:

(i) A medium is provided to transfer heat away from the core.
(ii) It may help collapse the upper head steam void which enables RCS pressure reduction.

Negative effects:

(i) A possible high pressure spike is generated when water is added to an overheated core.
(ii) Hydrogen may be generated as a result of the zirconium–water reaction.
(iii) Injection of un-borated water may lead to re-criticality.
(iv) A steam explosion is possible if the injection rate is too fast.

b) Inject water into SGs

Positive effects:

(i) Heat removal from the secondary side is provided, which could lower the primary pressure and promote primary side water injection.

(ii) The tubes are protected from over temperature conditions and the possibility of tube creep rupture is reduced.

(iii) Fission products are scrubbed if SG tube leakage has occurred.

Negative effects:

(i) Thermal shock from feeding a dry SG could cause the tubes to fracture.

(ii) Creep rupture of tubes could occur when a hot, dry SG is fed by lowering the pressure on the secondary side of the tubes.

c) Depressurization of the SGs

Positive effects:

(i) Lower pressure water pumps can be used to feed the SG.

(ii) Heat is removed from the primary side of the SG.

Negative effects:

(i) Creep rupture of the SG tube may be possible due to depressurization of the secondary side of the SG and promotion of circulation on the primary side of the tubes.

(ii) If developed head of low pressure water pumps are sufficiently low, SG dryout may be necessary to reduce the pressure enough to allow feed.

d) Restart of RCPs

Positive effects:

(i) Any water volume in the cross under pipe will be sent to the core, which removes heat and offers some temporary retardation of core melt.

(ii) A recirculation path with the SG for reflux cooling could be established.

Negative effects:

(i) A recirculation pathway to the SG can be started and, if any SGs are dry, tube creep potential is increased.

e) Flooding of the reactor cavity

Positive effects:

(i) Vessel failure can be prevented or delayed (to avoid creep rupture of the vessel) if the water level inundates the vessel sufficiently.

(ii) A heat sink for the RPV is provided and reactor coolant boil-off is reduced, provided the RPV insulation does not prevent the submerged vessel from steaming.

(iii) The corium–concrete interaction is reduced if the RPV fails, even if the cavity is covered by only a small amount of water.

Negative effects:

(i) If flooding is accomplished by containment spray, condensation of steam in the containment can result in to 'de-inerting', which can increase the possibility of a hydrogen combustion.

(ii) Extended water injection into the containment could submerge safety related equipment.

(iii) Extended injection of external water sources into the containment could cause long term corrosion cracking concerns.

(iv) A steam explosion is possible.

f) Depressurization of the RCS

Positive effects:

(i) A low pressure water make-up system is allowed to supply water to the RCS.

(ii) Stress in the primary system is reduced, thereby decreasing the probability of creep rupture of SG tubes or reactor coolant system piping.

(iii) The effect of high pressure RPV failure is reduced, i.e. DCH concerns and corium relocation outside the RPV.

g) Spraying water into the containment

Positive effects:

(i) The pressure and temperature in the containment is reduced, thereby reducing the challenge of containment failure and leakage.

(ii) The airborne fission products are washed out, thereby reducing their release through any containment leakage.

(iii) Cavity flooding is promoted.

Negative effects:

(i) Condensation of steam in the containment can result in to 'de-inerting', which can increase the possibility of a hydrogen combustion.

h) Operation of containment fan coolers

Positive effects:

(i) The pressure and temperature in the containment is reduced, thereby reducing the challenge of containment failure and any leakage.

Negative effects:

(i) Condensation of steam in the containment can result in to 'de-inerting', which can increase the possibility of a hydrogen combustion.

i) Venting of the containment

Positive effects:

(i) The pressure in the containment is reduced, thereby reducing the challenge of containment failure

(ii) Reduction of ground level releases

(iii) Reduction of mass of hydrogen in the containment

(iv) Trapping of fission products in scrubbers and filters

Negative effects:

(i) Release of FPs if filtering and scrubbing are not efficient

(ii) De-inerting of the containment

(iii) Hydrogen combustion in the vent line.

APPENDIX-B: TYPICAL PLANT PARAMETERSUSED IN ACCIDENT MANAGEMENT PROGRAMME

B.1 Following is the typical plant parameters used in accident management programme of water cooled reactors:

(i) SG water level
(ii) SG pressure
(iii) Primary heat transport system/reactor coolant system pressure (pressuirser pressure, accumulator pressure, safety injection header pressure)
(iv) Emergency core cooling system (ECCS) flow rates
(v) Position of pressurizer relief valves
(vi) Position of isolation valves on the main steamline
(vii) Water level in spent fuel pool
(viii) Dose rate at the plant site
(ix) Containment pressure and temperature
(x) Hydrogen, oxygen and steam concentration in the containment
(xi) Location of core debris: temperature (e.g., in different containment compartments and/or embedded in structures where the corium is expected to relocate)
(xii) Success of water injection and cooling functions: reactor vessel/primary heat transport system pressure and temperature, calandria and calandira vault water level, pressure and temperature, containment pressure and temperature, water levels at relevant locations, temperatures in the cooling chain and flow rates of cooling systems
(xiii) Radiation levels in the containment, site releases, radiation activity measurements in release routes (e.g. use of online decision support system)
(xiv) Post-accident sampling of containment environment
(xv) Monitoring the position of isolation valves and other important valves
(xvi) Integrity of the steam generator tubes: reactor coolant system temperature, activity in secondary side

B.2 Symptoms generic to LWRs:

(i) RPV level
(ii) Emergency condenser level, pressure, temperature
(iii) Core temperature (RCS temperature, RPV metal temperature, core exit temperature, hot/cold leg temperature difference, sub-cooling margin)
(iv) Pressure vessel melt through: temperature or other suitable parameters (e.g., outer wall of the RPV)
(v) Water level in the containment (containment recirculation sump level, Re-fuelling Water Storage Tank level)
(vi) Containment pressure
(vii) Water level in the reactor cavity
(viii) Re-criticality: neutron flux measurements or relatable parameters[25]

[25]Survivable instrumentation can be used as long as the core is within the pressure vessel; sharp increase (unexpected behaviour) in containment pressure and temperature measurements may be an indication of re-criticality

(ix) Temperature of the corium for RPV breach
(x) Temperature in the core catcher
(xi) Water level in the core catcher
(xii) Temperature of reactor cavity concrete

B.3 Symptoms generic to PHWRs

(i) Water level in decay heat removal condenser
(ii) The PHT temperature (PHT temperature, RIH/ROH temperature difference, sub-cooling margin)
(iii) The water level in the containment (sump/suppression pool level)
(iv) The calandria level
(v) The calandria vault level
(vi) The temperature of the calandria vault water

APPENDIX-C: TYPICAL EXAMPLES OF PLANT DAMAGE CONDITIONS

The term 'plant damage condition' is used to describe the degree of damage to the reactor core including fuel, the reactor pressure vessel/coolant channel/calandria/calandria vault and the containment. Typical categorisation of the damage conditions in increasing severity of the postulated accident are described below for water cooled reactors and may adopt a different categorisation based on present state-of-art:

C.1 The plant damage conditions may be classified as follows for PWRs and BWRs:

The following are the typical damage conditions for the core:

a) **Oxidised fuel:** This damage condition represents degraded fuel conditions in which the fuel cladding has undergone oxidation but fuel degradation is not sufficient to lead to appreciable relocation of fuel debris. In this state, the coolable geometry of the fuel does not differ significantly from that before the initiation of fuel damage. This damage condition is applicable to fuel both in the reactor core and in the spent fuel pool.

b) **Badly damaged core:** This damage condition represents a degraded fuel condition in which significant fuel relocation has occurred so that the coolability of the fuel geometry has degraded. One consequence of such fuel relocation is to introduce flow blockages in the fuel matrix. These blockages serve to limit the access of cooling water to the fuel material. This damage condition is applicable to fuel both in the reactor core and in the spent fuel pool. This damage condition for fuel in the reactor core will include potential challenges to the integrity of the RPV lower head. Similarly, this damage condition for fuel in the spent fuel pool will include potential challenges to the spent fuel pool structure.

c) **Core ex-vessel:** This damage condition represents a degraded fuel condition in which core debris has relocated into containment. This is the damage state in which direct attack of the concrete containment can occur. This damage state is of relevance to degraded reactor core fuel.

The following are the typical damage conditions for the containment:

a) **Containment closed and cooled**[26]: This damage state represents a condition in which the containment is intact and no appreciable build-up of energy is occurring within the volume. This damage state applies to both the primary and secondary containments.

b) **Containment challenged:** This damage state represents a situation in which either appreciable quantities of energy have built up within the containment volume or flammable gases are present in a mixture that could ignite given the presence of an ignition source. Such a damage state applies to both the primary and secondary containments.

c) **Containment impaired:** This damage state represents an impaired containment state

[26] This is not really a containment damage condition, but is a relevant plant damage condition if associated with one of the mentioned core damage conditions.

in which either containment isolation is not complete or a breach of containment has occurred by some other means. This damage state applies to the primary containment.

d) **Containment bypassed:** This damage state represents conditions in which there is a breach in the reactor coolant system that could bypass the containment boundary.

C.2 The plant damage conditions may be classified as follows for PHWRs:

a) **Damage condition 1:** The fuel channels have lost water inventory, dried out and heated up. The fuel sheath is oxidized and the pressure tubes have ballooned/sagged into contact with the calandria tubes. The moderator removes most of the decay heat.

b) **Damage condition 2:** The moderator level has dropped exposing several upper channels (due to moderator rupture disk bursting due to boiling or in-core LOCA). The exposed channels have heated up, sagged, oxidized and broken apart collapsing onto lower submerged channels or dropping to the bottom of the calandria vessel. Most of the decay heat is removed from submerged channels as well as some of the decay heat of the collapsed fuel channels that are now submerged.

c) **Damage condition 3:** The moderator inventory is exhausted (boiled off slowly or drained quickly due to type and location of break). All channels have heated up, sagged, oxidized and broken apart leaving a rubble pile of ‘corium’ (mix of fuel and core structural materials) at the bottom of the calandria vessel. The steel calandria vessel and surrounding biological shielding materials (water, or concrete) remove some of the decay heat. The structure is not capable of removing all decay heat and the corium will eventually melt through; however, adding water to the calandria vault can prolong this state.

d) **Damage condition 4:** Corium has penetrated through the calandria vessel and is on the concrete floor. Accumulated water may quench the molten corium.

e) **Damage condition 5:** Due to lack of water or insufficient contact area for boiling, or due to formation of an upper crust, the corium attacks the concrete referred to as molten core concrete interaction. Ablation of concrete produces steam, H_2, CO and CO_2. The degree to which the molten core concrete interaction can be terminated depends on the decay heat (which diminishes with time), the surface area of the melt (affects rate of cooling by a water layer, limited by the critical heat flux) and the availability of water.

The damage states with respect to containment for LWRs discussed above are also applicable to PHWRs.

APPENDIX-D: TYPICAL LIST OFPARAMETERS FOR ENTRY/EXIT CRITERIA

Transition from the EOP domain to the SAMG domain should take place if preventive accident management is unsuccessful. The SAMG should specify the parametric values for the transition along with its justification. The transition is based on symptoms indicating the onset of fuel damage or the fact that fuel damage is imminent. This is done by recognising certain representative and measurable plant parameters, e.g. the core exit temperature (typically for PWRs) or the failure to maintain a minimum level in the RPV (typically for BWRs) or by defining thresholds, or using recognised and predefined degraded states based upon the analysis of a set of related parameters.

Termination and exit from SAMGs should be specified in addition to entry criteria. The exit conditions should be based on measurable data indicating that safe and stable conditions have been successfully achieved.

Typical entry criteria parameters for SAMG in PHWRs, PWRs and BWRs are given in D.1, D.2 and D.3 respectively. Shutdown states may have additional/separate criteria parameters. Typical exit criteria parameters is given in D.4.

D.1 Entry criteria parameters for PHWRs

(i) Sub-cooling margin in inlet/outlet headers
(ii) Moderator low level
(iii) Radiation level in the containment
(iv) Steam generator low level

D.2 Entry criteria parameters for PWRs

(i) RPV flooding not successful
(ii) Core exit temperature and/or ECCS is not available
(iii) Superheat on the core exit temperature thermocouple
(iv) Radiation level in the containment

D.3 Entry criteria for BWRs

(i) Minimum cooling level in RPV
(ii) Radiation level in the containment

D.4 Entry criteria for SFPs

(i) Spent fuel pool level going below alarm level
(ii) Spent fuel pool water temperature
(iii) Dose rate

D.5 Exit criteria

(i) Reactor core temperature < X* AND stable or decreasing
(ii) Dose rate< Site emergency levels AND stable or decreasing
(iii) Pressure inside containment < X* AND stable or decreasing
(iv) Hydrogen concentration inside containment < 4% in dry air AND stable or decreasing
(v) Availability of ultimate heat sink

*X = Certain value of a given parameter

APPENDIX-E: COMPUTATIONAL AIDS

The stress level of all personnel will be high during the accident progression. Therefore, by reducing the potential for human error, ease of application will increase the overall success of the response organization. One of the possible ways of accomplishing this is to develop calculation methods that may be used by the evaluators/implementers in mitigating plant damage. Some of these could be developed prior to an actual event. Such computational aids are presented in the form of parameter graphs, diagrams, tables, etc. The following is the typical list of computational aids:

(i) RCS injection timing/rate to recover core
(ii) Coolant injection rate need for the removal of decay heat from the core, heat from metal oxidation and accumulated heat of the RPV structural material
(iii) Coolant injection rates to calandria and/or calandria vault required
(iv) Injection rate for long term decay heat removal
(v) Amount of water that will prevent vessel melt through or calandria failure
(vi) Minimum water injection rate for retention of debris in RPV (BWRs)
(vii) Amount of water needed of effectively spray cool the containment
(viii) Hydrogen production
(ix) Containment atmospheric flammability
(x) Volumetric release rate from vent
(xi) Effect of containment venting on the flammability of hydrogen in the containment
(xii) Containment challenge – to determine whether depressurising the containment may induce a (future) hydrogen challenge or burn
(xiii) Containment water level and volume (correlation between injected water and containment water level to determine the flooding level)
(xiv) RWST gravity drain initiation and level (to estimate the flow rate into the containment by gravity drain from the RWST)
(xv) Potential for re-criticality
(xvi) Time available for reaching different criteria
(xvii) Measuring the containment pressure and reading the hydrogen concentration may give an immediate insight whether or not the containment is challenged

ABBREVIATIONS

AC	Alternating Current
AERB	Atomic Energy Regulatory Board
AMG	Accident Management Guidelines
AMP	Ageing Management Programme
AOO	Anticipated Operational Occurrences
BWR	Boiling Water Reactor
CA	Computational Aid
DBA	Design Basis Accident
DC	Direct Current
DCH	Direct Containment Heating
DEC	Design Extension Conditions
DID	Defence in Depth
DSA	Deterministic Safety Analysis
ECCS	Emergency Core Cooling System
EOP	Emergency Operating Procedure
EPR	Emergency Preparedness and Response
IAEA	International Atomic Energy Agency
LOCA	Loss of Coolant Accident
LWR	Light Water Reactor
MCR	Main Control Room
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
NRE	Nuclear and Radiological Emergency
OESC	On-site Emergency Support Centre
PHT	Primary Heat Transport System
PHWR	Pressurised Heavy Water Reactor
PWR	Pressurised Water Reactor
PSA	Probabilistic Safety Assessment
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RIH	Reactor Inlet Header
ROH	Reactor Outlet Header
RPV	Reactor Pressure Vessel
RWST	Refueling Water Storage Tank
SAM	Severe Accident Management
SAMG	Severe Accident Management Guidelines
SBO	Station Black Out
SFP	Spent Fuel Pool
SG	Steam Generator
SSC	Systems, Structures and Components

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